Enhancements of mechanical properties of friction stir welding for 6061 aluminum alloy by Friction Stir Processing (FSP) method.

Ali A. Salman (Msc student)
Department of materials Engineering
Al-Mustansiriyah University
College of Engineering

1Asst.Prof.Dr. Ayad M. Takak
Department of prosthetic and orthotic Engineering
Al-Nahrain University
College of Engineering

As. Prof. Dr. Kadhim K. Resan
Department of materials Engineering
Al-Mustansiriyah University
College of Engineering

***Abstract*- Friction stir processing is a new method of changing the properties of a metal through intense, localized plastic deformation ,this process mixes the material without changing the phase (by melting or otherwise) and creates a microstructure with fine, equiaxedgrains, It is used to improve the microstructural properties of metals.**

In this paper, the enhancement of mechanical propertiesof friction stir welding specimens at variable rotation speeds (1100, 1300 and 1500 rpm) with constant feed speed (60mm/min) for 6061-T6 aluminum alloy is studied by using the friction stir processing method at the same variable rotation speed and feed speed in order to transform a heterogeneous microstructure to a more homogeneous, refined microstructure.

The best results of the welding line at the parameter 60 mm/min weld speed and 1300RPM rotation speed for the friction stir welding (FSW) and friction stir processing (FSP) where the efficiency reaches to 84.61% for FSW and 89.05% for FSP of the ultimate tensile strength of the parent metal.

Keywords: friction stir welding (FSW) , friction stir processing (FSP) , rotating speed , microstructure ,efficiency , Micro hardness .

1. Introduction

Friction stir processing is based on friction stir welding (FSW) which was invited by the Welding Institute (TWI) of United Kingdom in 1991[1].

Friction stir processing (FSP) is a new microstructural modifications technique; recently it FSP has become an efficient tool for homogenizing and refining the grain structure of metal sheet. Friction stir processing is believed to have a great potential in the field of superplasticity in many Al alloy [2].

Friction stir processing (FSP) is a solid-state process which means that at any time of the processing the material is in the solid state. In FSP a specially designed rotating cylindrical tool that comprises of a pin and shoulder that have dimensions proportional to the sheet thickness [3]. The pin of the rotating tool is plunged into the sheet material and the shoulder comes into contact with the surface of the sheet, and then traverses in the desired direction. The contact between the rotating tool and the sheet generate heat which softens the material below the melting point of the sheet and with the mechanical stirring caused by the pin, the material within the processed zone undergoes intense plastic deformation yielding a dynamically-re crystallized fine grain microstructure as show in figure (1).

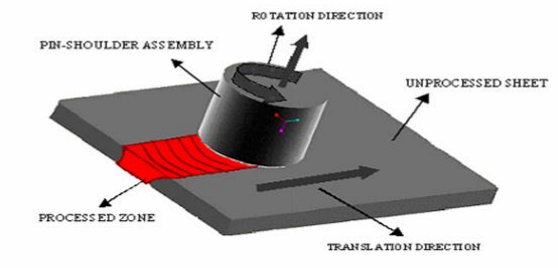


Fig.1 Schematic of friction stir processing (FSP) [5]

Experimental work

In this study 6061-T6 AA was selected , and it is selected because have high characteristics and Excellent joining characteristics, good acceptance of applied coatings. Combines relatively high strength, good workability, and high resistance to corrosion and widely applications are Aircraft fittings, camera lens mounts, couplings, marines fittings and hardware, electrical fittings and connectors, decorative or misc. hardware, hinge pins, magneto parts, brake pistons, hydraulic pistons, appliance fittings, valves and valve parts; bike frames [6]. The standard mechanical properties and chemical composition of 6061-T6 AA is given in Table 1 and Table 2 respectively. To carry out FSW and FSP process two aluminum plates 3 mm in thickness, 200 mm length, and 75 mm width as show in Figure (2), a clamping fixture was utilized in order to fix the specimens to be welded on a Hermen milling machine Figure (3).

Table 1: Mechanical properties of 6061-T6 AA

	Ult. strength (MPa)	Yield strength (MPa)	Modulus of elasticity (GPa)
Standard	310	276	68.9
Measured	325.306	290.55	69.3

Table 2: Chemical Composition of 6061-T6 AA

	Mg	Si	Cr	Mn	Ti	Cu	Zn	Fe	Al
Standard	0.8-1.2	0.4-0.8	0.04-0.35	Max 0.15	Max 0.15	0.15-0.4	Max 0.25	Max0 .7	Balance
Measured	0.95	0.65	0.068	0.055	0.038	0.34	0.18	0.57	Balance

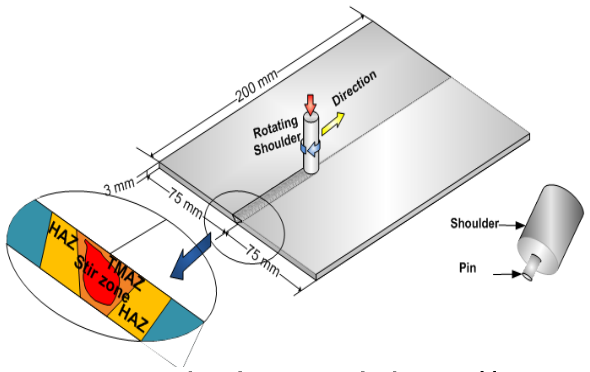


Fig.2 6061-T6 AA plates dimensions and Schematic of friction stir welding (FSW)

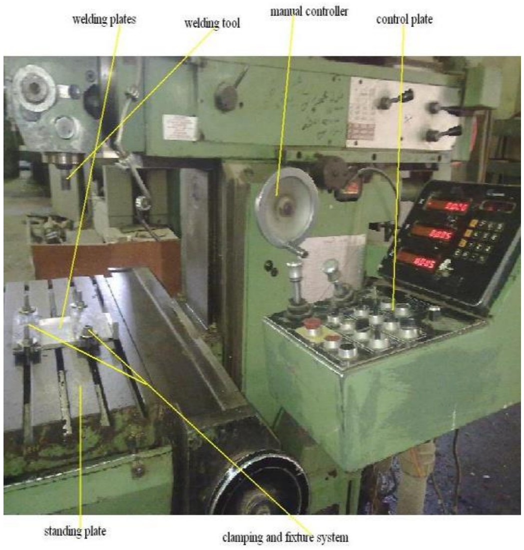


Fig.3 Hermen milling machine

Specially prepared stirrer Figure (4) was pressed against the bonding line and the welding process was started. The length of the stirrer was same as the required welding depth. The welding process was carried out by rotating the stirrer at different rotational and welding speeds under a constant friction force.

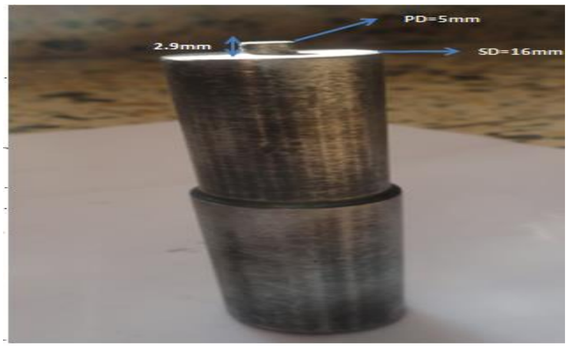


Fig.4 Tool for FSW and FSP

Understanding the tool design plays a very important role in FSW and FSP products. The initial FSW&FSP tool designed was a simple cylindrical tool with 16 mm shoulder diameter and 5 mm pin diameter, height of the pin equal to the distance that plunged in the plate and it was 2.9 mm of the sheets processed. The forces generated using this tool especially during the penetration of the tool into the work piece, were very high and caused excessive machine vibration. The welding tool was made of tool steel X38 as the chemical composition shown in Table 3.

Table 3: Chemical Composition of welding tool

C	Si	Mn	P	Cr	Ni	Mo	Co	Fe
0.88-0.96	0.16	0.40	0.03	0.03	-	4.7-2.0	4.5-5.0	**Balance**

The tool pin is brought in contact with the workpiece's top surface and the tool is put into rotation using digit control part and the welding speed is controlled by the digital spindle to get the desired welds and then the pin of the FSW tool is forced into the workpiece while it is rotating at the desired rotational speed, and the shoulder becomes in contact with the surface of the workpiece. The rotating FSW tool is then transverse along the desired direction at specific welding speed to complete FSW.

And then at the same rotation and traverse (Feed) speed in Table (3) return in reverse direction Until reaching the starting point for welding to produce FSP. As show in figure (5)

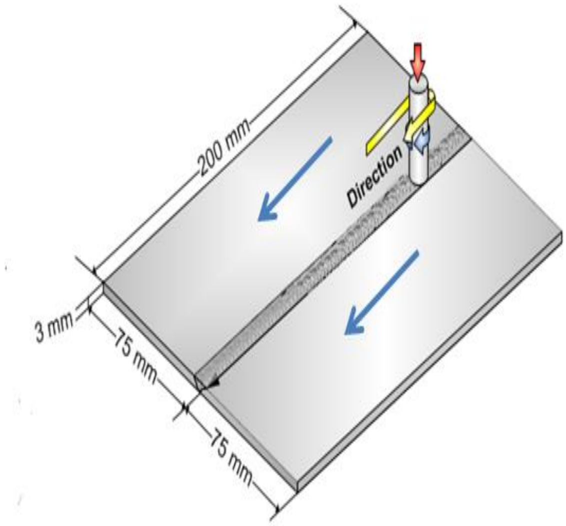


Fig.5 FSP process for 6061 – T6 plates

FSW & FSP is done following the conditions that are shown in Table 4.

Table 4: FSW & FSP process parameters variables

Type of welding	Rotation speed (RPM)	Traverse (feed) speed (mm/min)
FSW1	1100	60
FSW2	1300	60
FSW3	1500	60
FSP1	1100	60
FSP2	1300	60
FSP3	1500	60

Tensile Test

A simple tensile test was carried out using a tensile testing device, type Testometric shown in Figure (6), at a speed of 10 mm /min to the test specimens of 6061-T6 aluminum alloy were prepared following the ASTM **E 8M** [8] standard specimen geometry shown in Figure(7).

Fig.6 tensile tester (testometric)

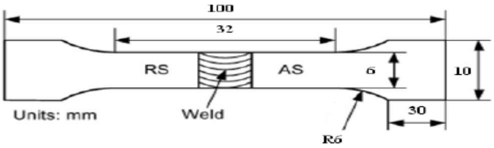


Fig.7 standard tensile specimen

And table (5) is explain the group for each condition of welding

Table 5: specimens the tensile of FSW and FSP

Name of group	Type of welding
A1,A2	FSW1
A3,A4	FSW2
A5,A6	FSW3
A7,A8	FSP1
A9,A10	FSP2
A11,A12	FSP3

and Figure (8) shows the tensile test specimens at different parameters before test.


Fig.8 the tensile test specimens

Microstructure test

The microstructures of welds produced for this project demonstrated all the characteristics of friction stir welds and this test is take place in three stages are involved grinding and polishing and etching in killers reagent is involved (2 ml HF , 3 ml HCL , 5ml HNO3 , 190 ml H2O) according to ASTM E407-76 . [9]

Results and Discussion

FSW Results

The friction stir welding (FSW) joints are shown in Figure (9).

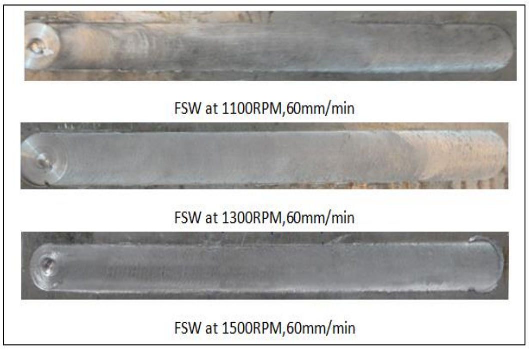


Fig.9 The appearance of upper surface of welding beads of 6061-T6 AA plates produced by FSW.

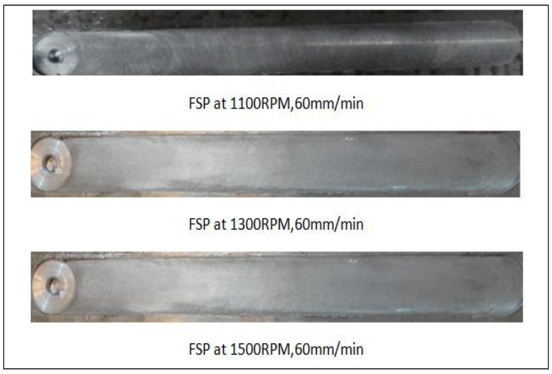


Fig.10 The appearance of upper surface of welding beads of 6061-T6 AA plates produced by FSP.

All welding lines of FSW and FSP are success by Visual inspection because of no defect or flash is found in plates and selection of rotation and welding (Feed) speed to reach the good appearance welding line .the rotation speed is less than 1100 RPM leads to bad welding line is due to non-reached to the re crystallization temperature and above of 1500 RPM is leads fusion of plates.

Tensile Results

Tensile specimens had been examined at room conditions as weld Figure (11).

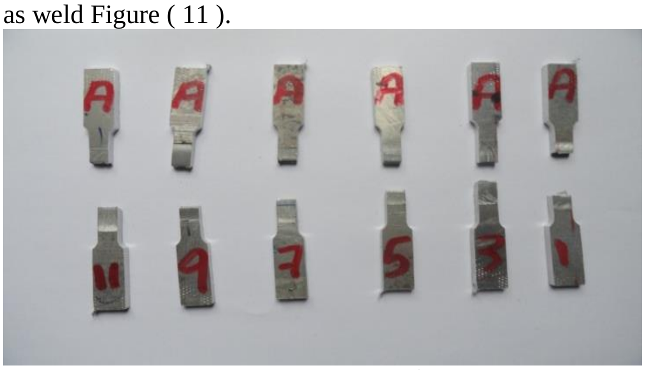


Fig.11 Tensile Test Specimen after testing

And the results for samples are explain in Table (6)

Table (6): results for tensile specimens

Name of group	Type of welding	Average of ultimate tensile strength (MPa)
A1,A2	FSW1	235
A3,A4	FSW2	275.253
A5,A6	FSW3	266.224
A7,A8	FSP1	263.75
A9,A10	FSP2	289.694
A11,A12	FSP3	276.72

And figure (12) show the values of ultimate tensile strength of specimens and ultimate tensile strength of base metal

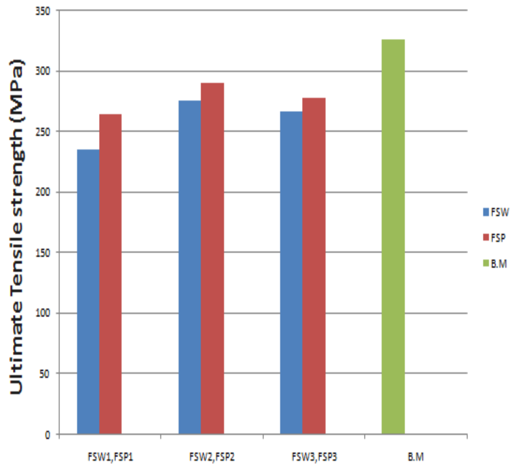


Fig.12 Tensile test results

Figure (13) show the efficiency for each case compare with base metal.

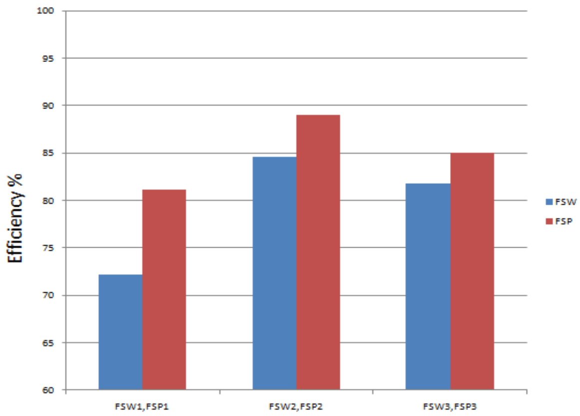
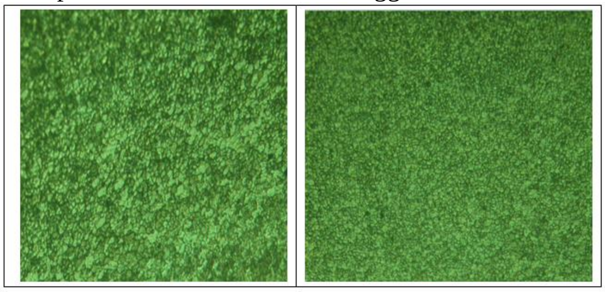


Fig.13 results of efficiency for tensile test

The optimum value was obtained at 1300 rpm rotating speed and 60 mm/min welding speed for both FSW & FSP , it was 275.253MPa and 84.61% for FSW and 289.694 MPa and the welding efficiency is 89.05% for FSP of the base metal that means FSP method is effective, it will give long life welds because of FSP is enhance the mechanical properties and modification of microstructure is leads to increase the mechanical properties.

Microstructure results

The optimum resulted from tensile test are both in FSW & FSP are examined in microstructure test and figure (14) are explain the microstructure of nugget zone in both cases



Nugget zone for FSW at 1300rpm,60m Nugget zone for FSP at 1300rpm,60mm/min

Fig.14 the microstructure of nugget zone in FSW and FSP

According to figure (14) the FSP is ultra-fining and modification of microstructure for nugget(welding) zone this refining leads to increase the mechanical properties and this microstructure is proved are no porosity or defect in welding (Nugget) zone in both cases.

Conclusion

1-

he highest strength of 6061-T6 for FSW and FSP at (1300 RPM and 60 mm/min) with the values of 275.253 MPa and 289.694 MPa for FSW and FSP respectively and 4.44 % the percentage of efficiency improvement by using FSP.

2- The highest Vickers hardness values of 6061-T6 AA are 98 and 107 for FSW and FSP respectively .

3- The friction stir processing is improved the micro structural properties at welding zones specially nugget zone and it caused grain refined of microstructure respect to friction stir welding.

References:

[1] **Powell, H.J. and Wiemer, K**., "Joining technology for high volume manufacturing of lightweight vehicle structures", TWI, Cambridge , 1996.

[2] **RAJESWARI R. ITHARAJU** "FRICTION STIR PROCESSING OF
ALUMINUM ALLOYS" University of Kentucky Master's Theses 2004 .

[3] **R. Nandan, T. DebRoy and H. K. D. H. Bhadeshia** "Recent Advances in Friction Stir Welding – Process, Weldment Structure and Properties" Materials Science 53 ,2008.

[4] **Thomas, W.M., Nicholas, E.D., Kallee, S.W.,** "Friction based technologies for joining and processing", Friction Stir Welding and Processing, Edited by K.V. Jata, M.W. Mahoney,
R.S. Mishra, S.L. Semiatin, and D.P. Field, TMS, 2001.

[5] **Mishra, R.S and Mahoney, M.W,** "Friction Stir Processing: A New Grain Refinement
Technique in Commercial Alloys", Materials Science Forum, Volumes357-359,2001.

[6] **R. S. Mishra, Z. Y. Ma and I. Charit**, "Friction stir processing: a novel technique for fabrication of surface

composite", Materials Science and Engineering A, Volume 341, Issues 1-2, 20 January 2010.
[7] The Aluminum Association, Standards and Data,2005.
[8] Test Methods for Tension Testing Wrought and Cast. Aluminum- and Magnesium-Alloy Products.
[9] **Myer Kutz** ,Mechanical Engineers' Handbook, Third Edition, Materials and Mechanical Design, 2006.